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When Do Planets Form? A Search for Extra-solar Planets Around Metal-Poor Stars

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Abstract. We present preliminary results from our spectroscopic search for planets within 1 AU of metal-poor field dwarfs using NASA time with HIRES on Keck I. The core accretion model of gas giant planet formation is sensitive to the metallicity of the raw material, while the disk instability model is not. By observing metal-poor stars in the field we eliminate the role of dynamical interactions in dense stellar environments, such as a globular cluster. The results of our survey should allow us to distinguish the relative roles of the two competing giant planet formation scenarios.

1. Introduction

The two proposed models for the formation of gas giant planets make different, and testable, predictions. For example, core accretion requires several Myr to grow a solid core massive enough to accrete a gaseous envelope (Lissauer 1993). In contrast, disk instability leads to Jupiter-mass clumps (e.g., Boss 1997), which can survive and give rise to actual protoplanets (Mayer et al. 2002), within $\sim 10^3$ yr. The time-scale for core accretion to proceed depends strongly on the initial surface density of solids (Pollack et al. 1996), so that formation by this mechanism may be enhanced in metal-rich stars. Instead, disk instability is remarkably insensitive to the primordial metallicity of the protoplanetary disk (Boss 2002). Several observational tests can be performed to probe giant planet formation models (Boss 2003). In order to unambiguously establish whether high primordial metallicity is a requirement, and thus determine which is the dominant formation mechanism for gas giant planets, we are conducting a spectroscopic search for planets orbiting a sample of metal-poor stars in the field, thus eliminating possible sources of interference with planet formation, or with migration to close-in orbits, or with planet survival, such as dynamical interactions in dense stellar environments.

2. Stellar Sample Selection

In this project we are searching for planetary companions within 1 AU orbiting a sample of 200 metal-poor dwarfs, chosen from the Carney-Latham (e.g., Carney et al. 1994) and Ryan (Ryan 1989) surveys of metal-poor, chromospherically quiet, non rotating ($V \sin i \leq 10$ km/s), high-velocity field stars that happen to be passing by the solar neighborhood. These stars are selected not to have close stellar companions based on long-term radial-velocity (RV) monitoring that has been carried out with the CfA Digital Speedometers. Our survey is orthogonal to other spectroscopic planet searches in that it spans a range of metallicities never investigated before ($-2.0 \leq$ [Fe/H] ≤ -0.6). We have further refined our sample of metal-poor dwarfs by imposing magnitude ($V \leq 11.5$) and temperature ($T_{eff} \leq 6250$ K) cut-offs, and utilized the metallicity, temperature, and magnitude constraints to compute the relative exposure times needed to achieve 20 m/s RV precision for planet detection. This precision is sufficient to achieve sensitivity to RV variations due to planetary companions with minimum masses in the average range $0.59 \leq M_p \leq 2.75$ M_J, or higher, for orbital periods in the range $0.01 \leq P \leq 1$ yr. Our sample of 200 metal-poor stars should eventually provide a robust 3-σ null result in the case of no detections.

3. Results

During the first two Keck 1/HIRES observing nights we have obtained spectra (1 template + 2 iodine exposures) for 40 stars covering a large range of metallicities and effective temperatures, with the primary aim of evaluating the RV precision as a function of effective temperature and metallicity, and thus test the validity of our predictions for the dependence of the RV precision on these two parameters. The resulting RV difference distribution between the two nights exhibits an rms residual velocity $\sigma \simeq 25$ m/s, corresponding to an expected single-measurement uncertainty of $\varepsilon = \sigma/\sqrt{2} \simeq 18$ m/s. No clear trends in the RV differences as a function of [Fe/H] and T_{eff} are present, a further confirmation that the model we developed for the dependence of the RV precision on the above parameters is robust. Our next goal will be to demonstrate the long-term stability of the velocity zero-point and expected single-measurement precision for planet detection.

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